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On-site oriented capacity regulation for fabrication shops in Engineer-to-Order companies (ETO)

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Abstract

Today many Engineer-to-Order (ETO) companies are under pressure to reduce their costs while minimizing the completion time on-site. ETO companies have worked in recent years to industrialize their manufacturing processes and to introduce prefabrication by standardization and modularization of their products. Less emphasis was set on organizing in an efficient way the installation supply chain. Considering tier one suppliers, which deliver their products to a building site for assembly, manufacturing should be driven according to the demand needed on the building site. Finished parts should be transported to the construction site Just in Time (JIT) with short lead times and low stocks in the fabrication shop and on-site. This requires for both, the construction site and the fabrication shop, a synchronous production and assembly planning. Therefore, an on-site oriented capacity regulation for fabrication shops is needed for ETO companies.

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1. Introduction

Industrial production can be classified according to different market interaction strategies: 1) Make-to-Stock, 2) Assemble-to-Order, 3) Make-to-Order and 4) Engineer-to-Order [1].

Up to now, research in construction and ETO companies has been focused on product development, while improvement in organizations and processes has been almost ignored [2]. In traditional ETO supply chains, manufacturing processes are disconnected from the installation on-site. This is emphasized by considering tier one suppliers, which produce and deliver their products to the site for assembly.

In recent years, the principles of industrialization and prefabrication of factory-finished elements have gained more and more acceptance in the construction sector [3]. However, due to a weak and non-synchronous production and installation planning, the prefabrication, transportation and installation cannot be aligned and used at full capacity. Therefore, a Just-in-Time (JIT) delivery of ETO components from prefabrication to the construction site is not possible. However, the JIT concept is one of the principles of Lean Production and nowadays of Lean Construction. By modern concepts such as Lean Production and Lean Construction, waste and lead times in the fabrication shop and on the construction site should be reduced [4]. While in the automotive or aerospace industry the application of Lean Manufacturing methods is common nowadays, the ETO environment is lagging behind these developments [5]. The installation of ETO-components (i.e. glass facades) in high-rise buildings can be affected through many disruptive factors, like the unpredictable availability of cranes and lifts, material damages, trade interferences and weather [6]. Therefore, ETO product development efforts have focused on prefabrication, performing as much assembly as possible before the elements arrive

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on-site, avoiding impact of disruptive conditions during installation [7].

Based on Lean Production, components should be produced error-free according to the customer demand. In ETO supply chains the installation on-site stands for the consuming process (customer). Prefabrication should be “pulled” according to the construction progress and performance, handling at the same time efficiently unpredictable events.

This paper describes a concept, elaborated within an industrial case study. The research team collaborated in this case study with the façade manufacturer of the expansion project of the central hospital of Bolzano in North Italy. The concept focuses on capacity regulation and production planning and control for glass facades (ETO-components).

2. Production planning in construction

The planning of construction projects is often of little detail resulting in high coordination effort, low productivity rates and delays in overall progress [8]. The so called “overall construction schedule”, which represents a project from start to finish, cannot be used for organizing in an efficient way the installation supply chain (prefabrication and transportation). So, a more detailed and process oriented schedule elaborated in a bottom-up approach is needed.

Within the Location-Based Management for Construction theory, traditional activity-based work breakdown structures are replaced by location breakdown structures. Kenley states that site confusion generally arises from traditional planning systems that provide a plan to the site which cannot be executed [9]. Unlike production, construction is organized around discrete activities which are organized in sequence but not by location [9]. To prevent traditional ways of construction disruptions, Kenley suggests a Location-Based Planning System. Location-Based Management assumes that there is value in breaking a project down into smaller locations and using these to plan, analyze and control work as it flows through these locations [10]. The Location-Based Management System (LBMS) is focused on long term planning avoiding construction interruptions between different trades.

For aligning in an efficient way the supply chain to the construction progress, a reliable and steady rate for installation has to be introduced on-site. In manufacturing, takt time planning is widely used for matching production cycle times to customer demand rate: Takt time is the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate) [11].

In construction up to now, some research has been done using the takt time principle [12] [13]. In [14] researcher have demonstrated that controlling the production of a concrete structure using small, repetitive cycles resulted in improvements in productivity, reductions in cycle times and reductions in waste. The takt time principle allows obtaining a demand rate driven Pull system with a steady production flow [11]. Enabling a production system to continuously flow helps production problems to come to the surface, so they can be addressed [15]. In construction the project is broken down in physical areas where trades may spend up to a certain amount of time (the takt time) in order to complete their elements of work [11]. In this paper the balancing act for preventing bottleneck processes is omitted and the focus is set on defining the appropriate productivity rate for every task.

So optimal intra-trade capacity utilization can be obtained and a reliable feedback about the installation progress for aligning the supply chain can be reached.

3. Concept for capacity regulation

Push systems are those where production jobs are scheduled, whereas Pull systems are those where the start of one job is triggered by the completion of another. In Push systems, like material requirements planning (MRP), an error in demand forecasts causes bullwhip effects. However in Just-in-Time (JIT) ordering systems, amplifications are avoided, because the actual demand is used instead of the demand forecast [16].

Two types of JIT ordering systems are generally used for supply chain management; KANBAN and CONWIP.

In manufacturing, a control loop steers the performance of a working process. According to the Value Stream Engineering (VSE) approach the flexible use of human resources is of primary importance [17]. At the consuming process the quantity of needed components is measured and then visualized at the producing process (controlled variable). The control loop can adjust the work capacity (correcting variable) in a certain range.

3.1 JIT-delivery (material flow)

The concept for aligning the material flow in ETO-supply chains is visualized in Fig. 1.

The fabrication shop is organized using a lean manufacturing supermarket. Manufacturing is based on lot sizes, i.e. the prefabrication of steel components or the pre-production of metal sheet components, which are stored in the supermarket and prepared for the final assembly process step. The supermarket as decoupling point (DP) divides the material flow in two stages: a lot size oriented prefabrication or preparation of components and raw materials and a customer oriented JIT-delivery of assembled façade elements. Based on the construction progress, especially the installation takt time, the final process step assembly is triggered. Assembled ETO-components are commissioned and prepared for transportation in a temporary shipping buffer.

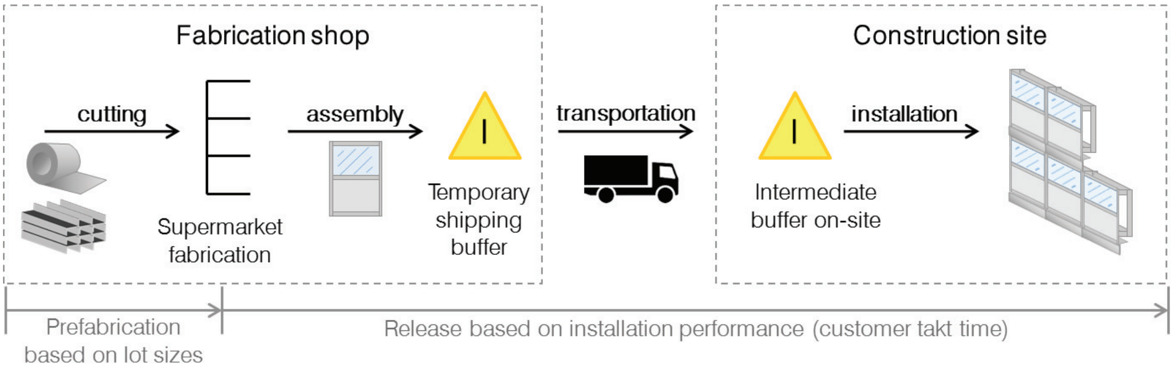

Fig. 1. Prefabrication and Just-in-Time delivery of façade elements on the construction site – material flow

The transport frequency and quantity is defined by considering a variable installation performance on-site. This means that, if installation (construction) performance decreases, due to unpredictable events (like weather conditions), production performance will be decreased without filling inventories. Otherwise, if installation performance increases on site, due an improvement in efficiency (like learning curve effects), production performance follows it avoiding construction stops. Then transportation components are stored in an intermediate buffer on-site. Place for storing materials is always scarce on the construction site, especially in urban areas and therefore it has to be organized in an efficient way.

Finally, ETO-components are moved with the crane into dedicated storing zones inside the building or installed directly on the façade following a planned sequence of installation.

3.2 JIT-regulation circuit (information flow)

The concept for the JIT-regulation circuit is visualized in Fig. 2 using the Value Stream Engineering (VSE) methodology. The installation process on-site is planned and measured in a detailed way. The tool for process planning and control is based on the rolling forecast approach. A daily installation process for (calendar week) CW+1 is planned starting from CW0. Prefabricated components, which are stored in the supermarket, are assembled Just-in-Sequence (JIS) according to the installation progress on-site.

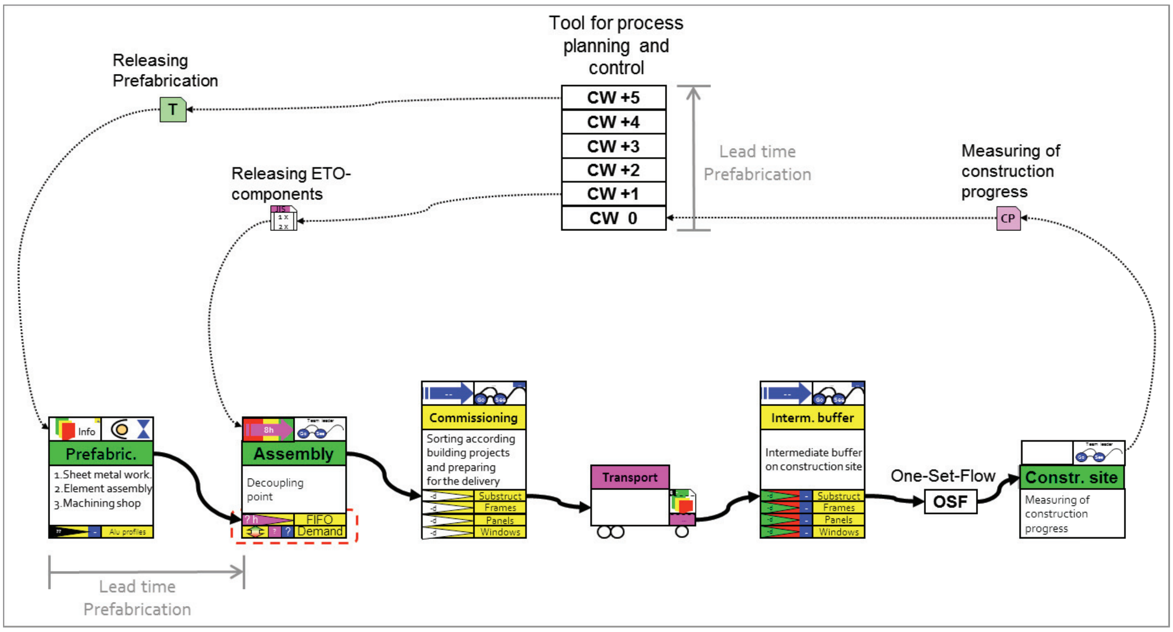

Fig. 2. JIT-regulation circuit – information flow

For triggering the prefabrication, a weekly forecast (CW+1 till CW+5) of needed components is performed. This forecast corresponds to the prefabrication lead time. So, two control circuits exist; one for triggering the prefabrication as well as the procurement of raw material and one for releasing the finishing and assembly of ETO-components shipping them Just-in-time (JIT) from the fabrication shop to the construction site.

In Fig. 3 the detailed approach for production planning in the fabrication shop and on-site is visualized. Considering production planning on the construction site, a crew is assigned for every task and a specific productivity index is estimated and periodically revised. The productivity index is composed of the number of construction areas per day. Furthermore, for every task on-site the corresponding component groups are defined in the bill of material. Based on the bill of material the quantity of subassemblies and components for every construction area are calculated. Thus, when the installation process on-site and the forecast of installation progress is planned, the type and number of construction components will be determined and sent to the production planning at the fabrication shop. Within the fabrication shop three main component groups are produced in different production areas: the production of covers through sheet metal working (component group A), the production of façade elements consisting of aluminum profiles and glass (component group B) and the production of steel substructures and frames (component group C).

As shown in Fig. 3 the construction site determines the customer takt time scheduling the installation tasks. This customer oriented Pull-control “Pulls” the needed components from the three production areas. The production in the fabrication shop distinguishes on-site orders for the assembly or finishing of façade components and prefabrication orders for cutting or preparing raw material. While on-site orders are demand-oriented and delivered Just-in-time, prefabrication orders are always lot-size oriented to maximize the utilization of machines and to obtain time reduction through economies of scale. This separation between lot size oriented prefabrication processes and on-site oriented assembly is called Decoupling Point (DP) and is represented through a physical supermarket for prefabricated components.

When productivity on-site is increasing, the system demands more components from prefabrication. When productivity on-site is decreasing, the system demands fewer components. So, a construction site oriented Pull-System can be introduced.

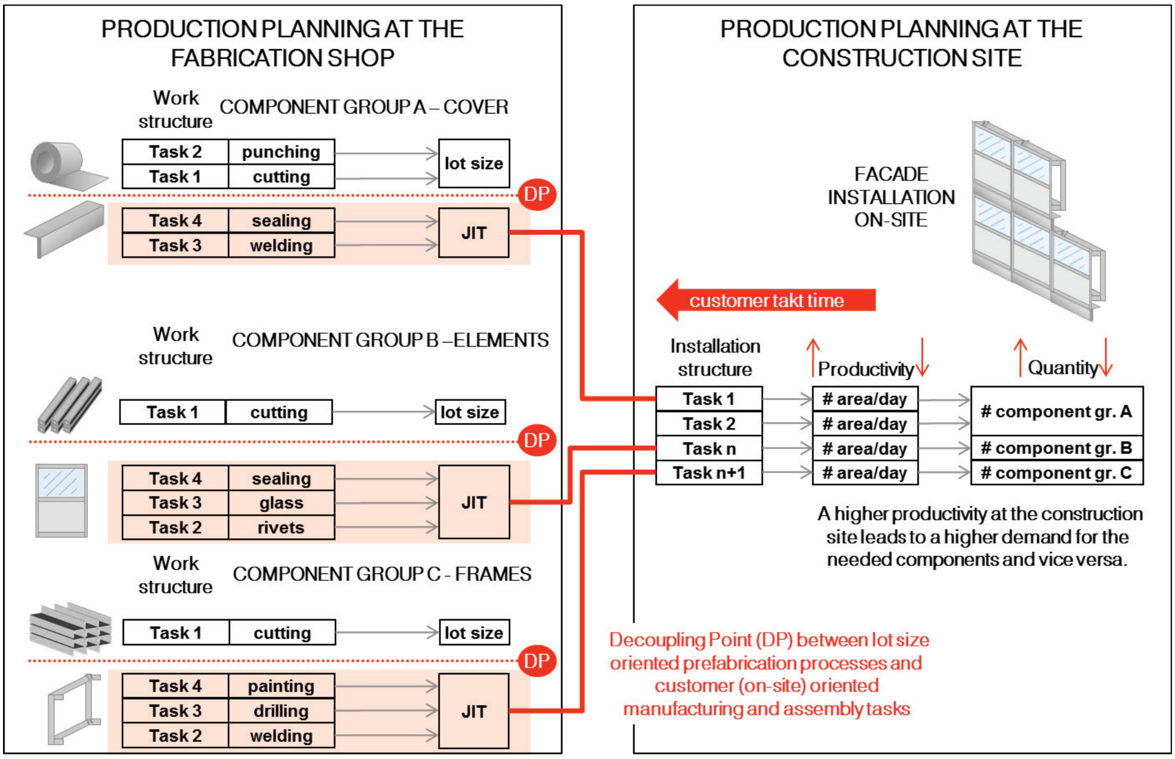

Fig. 3. Production planning on-site and in the fabrication shop

4. Implementation in an industrial case study

The case study treats the expansion project of the central hospital of Bolzano in North Italy. The enlargement project consists of an additional building for a new clinical section and stands currently for the biggest construction site in the region.
The enlargement project consists over ground of three wings (A, B and C) with respectively four levels, a north-wing with respectively three levels and a new entrance area (Fig. 4). The company Frener&Reifer GmbH (F&R) realizes, as leader company in a bidder-consortium, the facades of the tree wings (A, B and C). The construction site was launched by the bidder consortium at the end of April 2013 and goes on until the end of the year 2014. A research team composed of researchers from Fraunhofer IEC and the Free University of Bolzano was involved by F&R in the planning and execution phase of the project to develop a production planning and control concept at the construction site and its link to the fabrication shop.

Fig. 4 Enlargement project hospital of Bolzano

4.1 Case study objective and procedure

The case study consists in implementing the previous described methodology for capacity regulation in manufacturing and installation within the company F&R. During the first half of the year 2014 the concept will be tested in the expansion project of the central hospital of Bolzano. Within the second half of the year 2014 the methodology will be validated using a project with less repeatability of the installed components and façade elements. After this validation phase the concept should be generalized and introduced by F&R for all new and ongoing projects. The full implementation of the capacity regulation concept at F&R is planned by the beginning of the year 2015.

4.2 Impact of the approach

At the moment, for the company F&R, one of the major causes of budget overruns are personnel changes on the construction site. Due to an initial weak capacity planning, resources were moved between different construction sites and between manufacturing and installation.
Findings, up to now, have shown, that if the construction process is not disturbed (without replacing employees, without a lack of ETO-components on-site), big learning curve effects can be reached. Considering the example of the frame installation a 100% increase in productivity on-site is possible in a time horizon of three weeks.
When construction interruptions occur, a change of scheduled tasks on-site takes place, which leads consequently to rearranging materials or equipment on-site (therefore non-value-adding activities). Aligning manufacturing to the site could first of all avoid such non-value-adding activities. Furthermore, by reducing the manufacturing lot size, non-value-adding operations (like searching components on-site) could be avoided and the chances for early detection of quality problems could be improved.
Last but not least, by pulling manufacturing from site and defining a decoupling point in the manufacturing process a higher degree of flexibility, a better capacity utilization (in manufacturing and on-site), lower inventory stocks as well as a higher punctuality should be reached.

5. Conclusion and outlook

In usual Construction Supply Chains the three fields, prefabrication transportation and installation are not planned in a synchronous way. Thus, economic benefits reached in one field (i.e. prefabrication) are lost within the remaining ones. However, aligning the prefabrication lot size to the transport frequency/quantity and to the installation progress is a critical issue for a holistic optimization approach in ETO companies. Handling the high variability of construction processes and considering a multi-project environment are the future research challenges presented in this paper.
The suitability of the shown capacity regulation concept will be tested in the first half of the year 2014. The expected objectives like a higher productivity in the fabrication shop as well as on-site, lower inventory stocks in the supply chain and a transparent production planning will be monitored and evaluated at the end of summer 2014. In the second half of 2014 follows a second validation phase based on another case study and the elaboration of a specification and a prototype of a production planning and control IT tool.

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